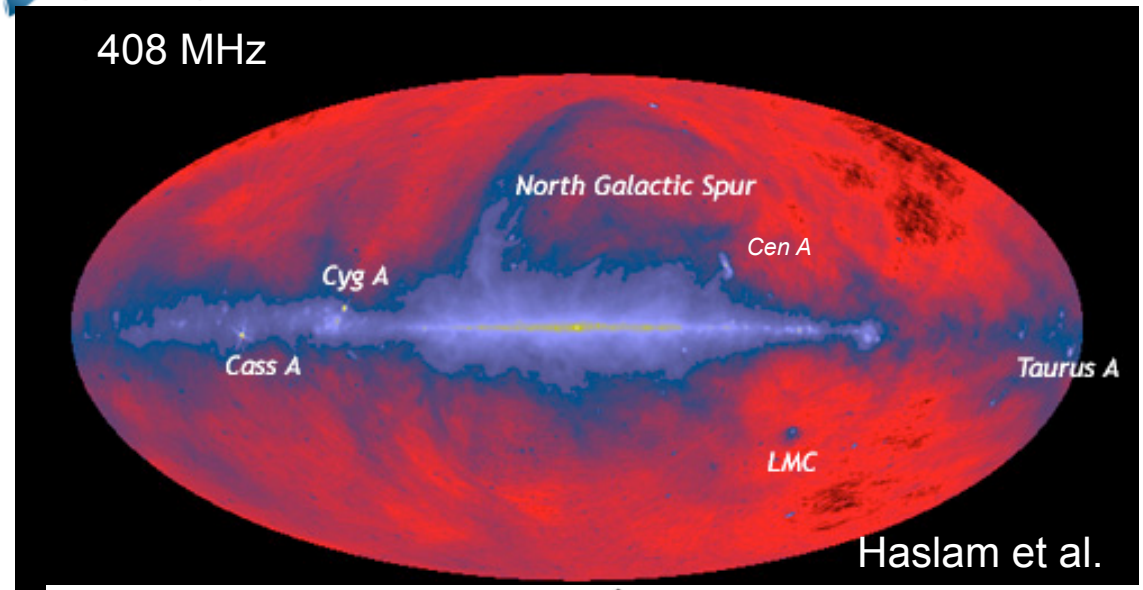

# The AGN Population in Radio and Gamma-rays: origins and present perspective

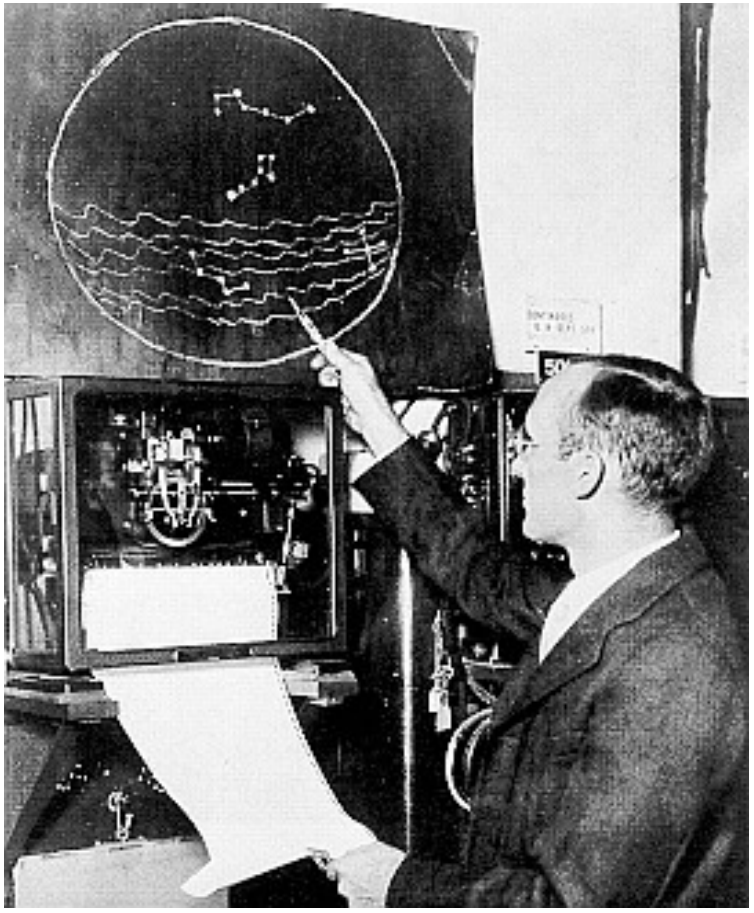
**C.C. Teddy Cheung**

**(NRC/Naval Research Lab)**

**on behalf of the Fermi-LAT Collaboration**

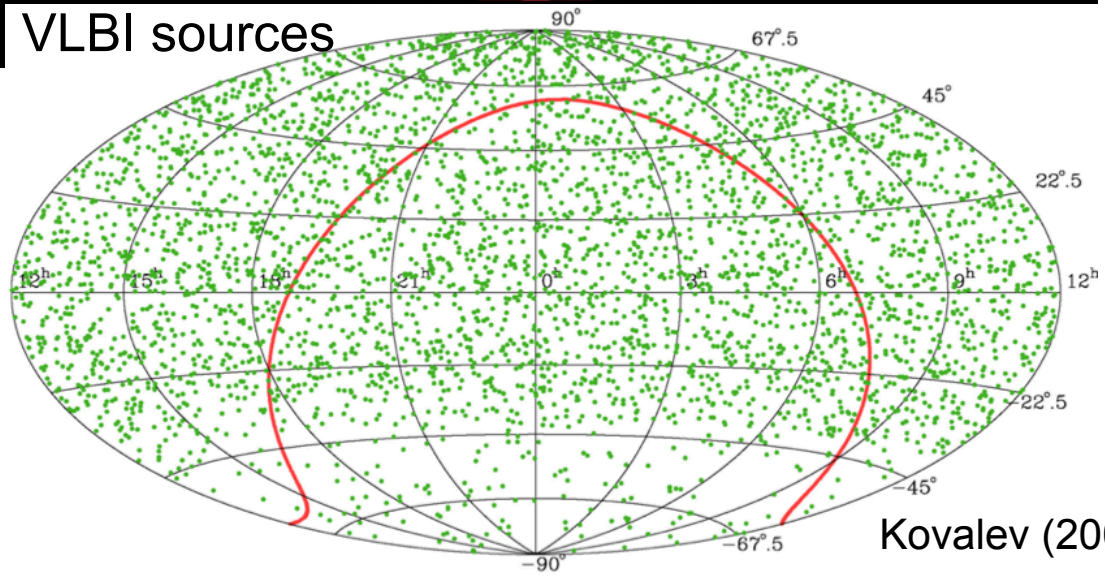
# Radio & Gamma-ray: Origins



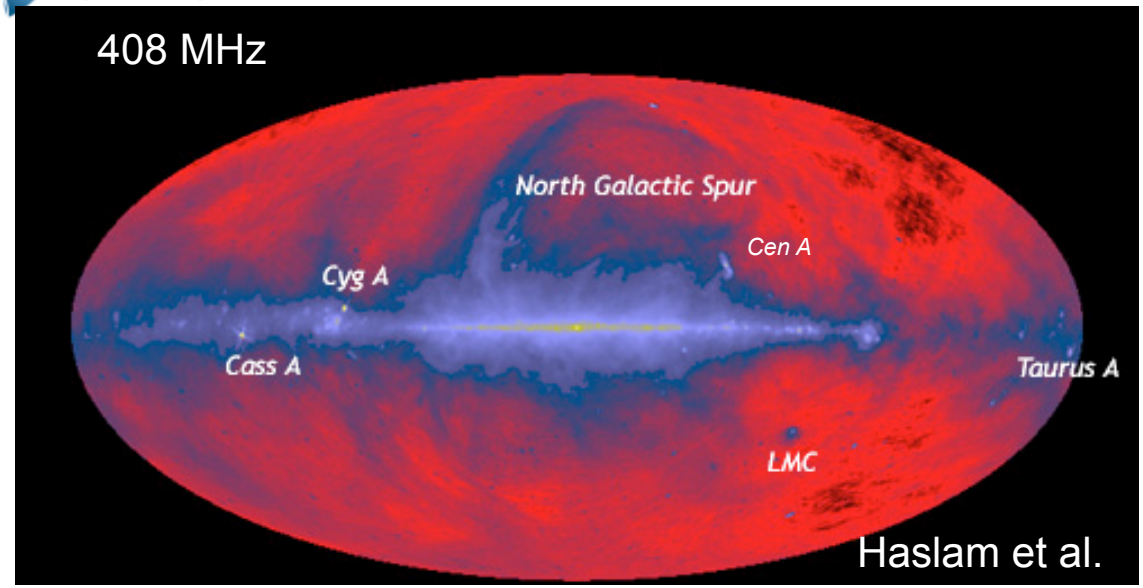
Karl Jansky, ca. 1930's
Grote Reber late 1940's

VLBI sources



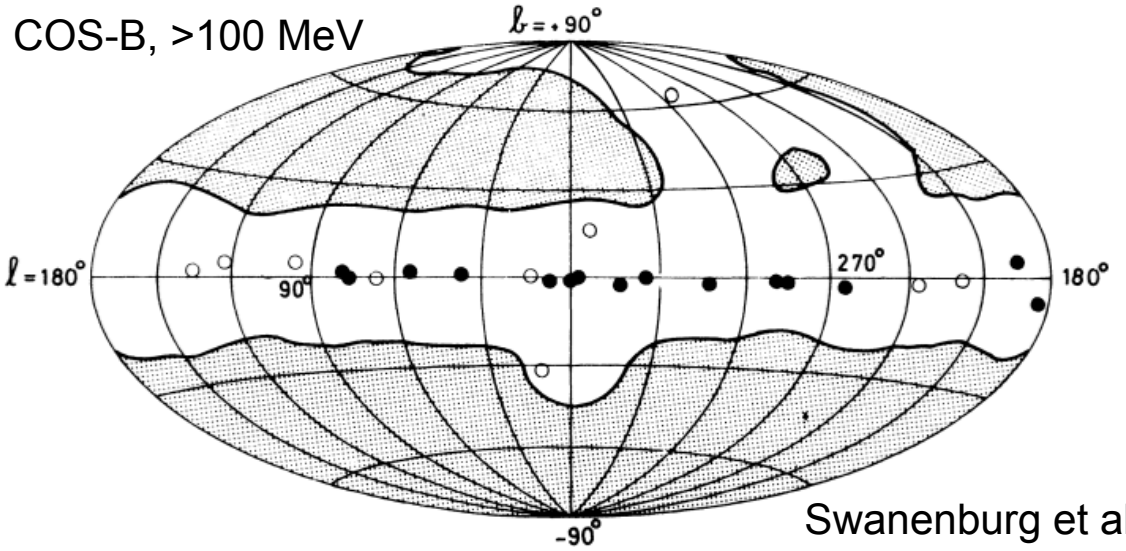

Kovalev (2009)

# Radio & Gamma-ray: Origins




### *Radio 1950's, early 1960's*

- Sources thought to be Galactic (Taurus A = Crab)
- Nearby galaxies Centaurus A, Cygnus A




Swanenburg et al. (1981)

### *γ-rays 1970's-1980's*

- Predominantly Galactic (Crab, Vela, Cyg X-3?)
- Extragalactic sources: 3C273, NGC1275

# Paradigm Shift: Radio

- 1950's: Radio sources thought to be local `radio stars'
  - supported by optical ID of Taurus A (Crab) by Bolton+ (1949)
  - Centaurus A and Virgo A (M87) were initially suggested IDs with galaxies (poor localizations); most source sizes >1 arcsec

- 1963: Quasars 3C48, 3C273 optically identified

***Paradigm shift: powerful compact radio sources***

***→ precise localizations were the key***

- Present rich phenomenology
  - superluminal motions
  - radio spectral polarimetric imaging on all scales (jets, hotspots)
  - abundant variety of sources including young radio sources, radio-quiet objects
- Radio stars orders of magnitude fainter than first debated sources

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***1970's – 1980's***
***SAS-2, COS-B***

- 1963: Quasars 3C48, 3C273 optically identified

***Paradigm shift: powerful compact radio sources***

***→ precise localizations were the key***

***1990's Compton***
***EGRET blazars***

- Present rich phenomenology
  - superluminal motions
  - radio spectral polarimetric imaging on all scales (jets, hotspots)
  - abundant variety of sources including young radio sources, radio-quiet objects
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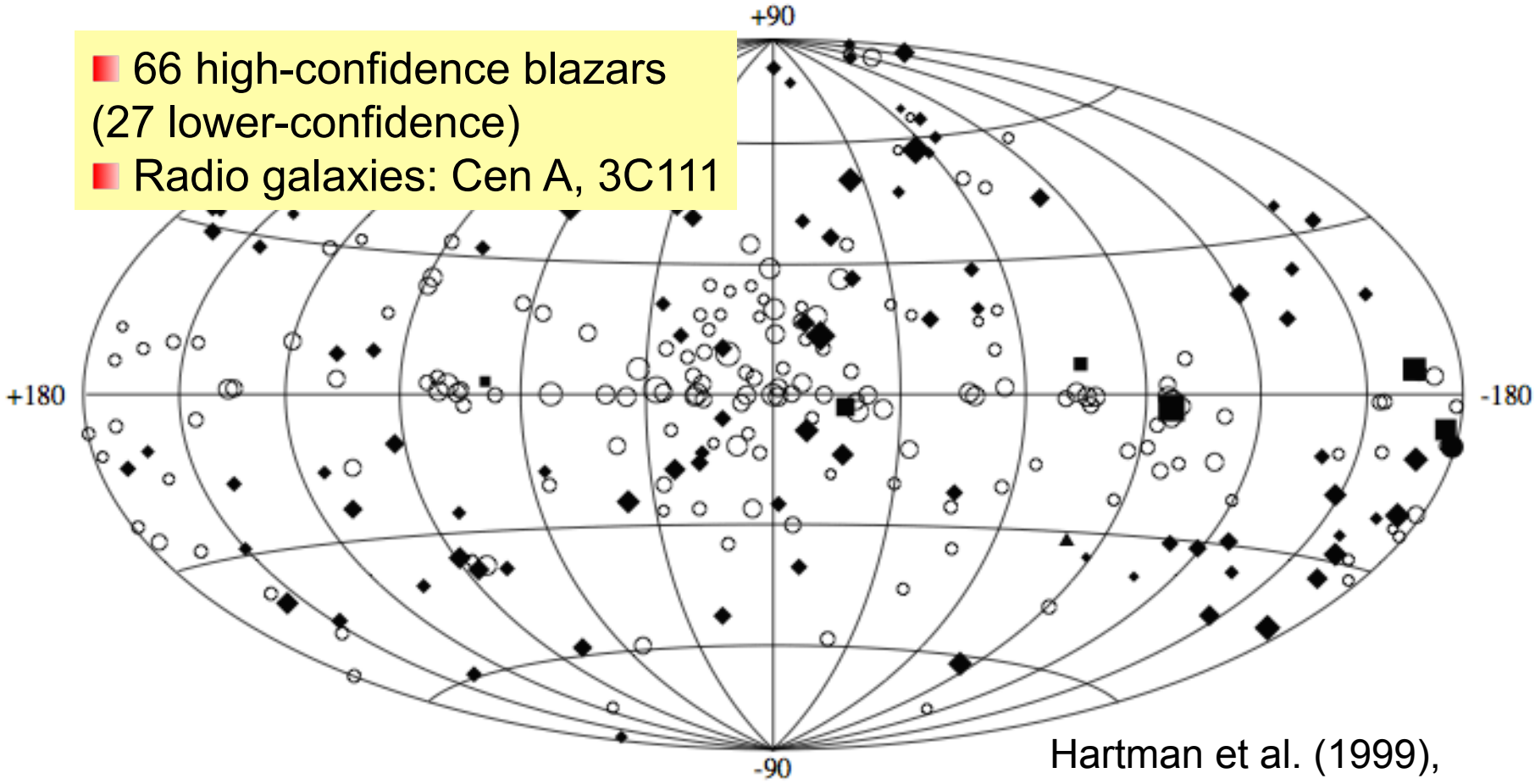
***Fermi LAT era***
***(you are here)***

# EGRET Era: Blazars

- 66 high-confidence blazars (27 lower-confidence)
- Radio galaxies: Cen A, 3C111




Hartman et al. (1999), Casandijian & Grenier (2008)

# EGRET Era: 3C279

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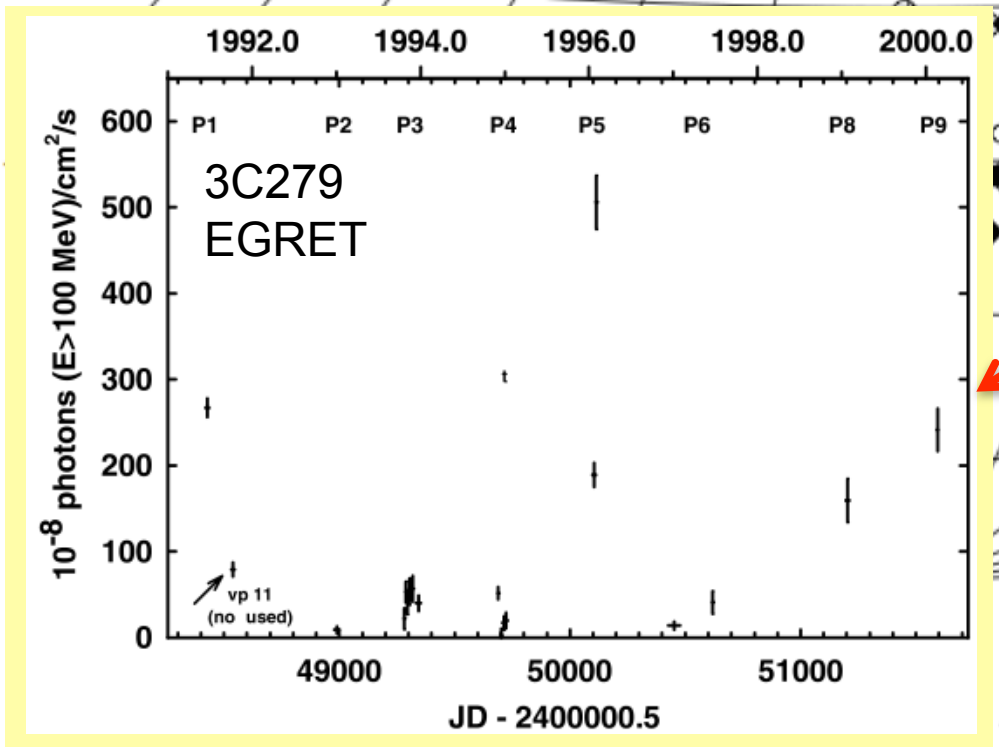
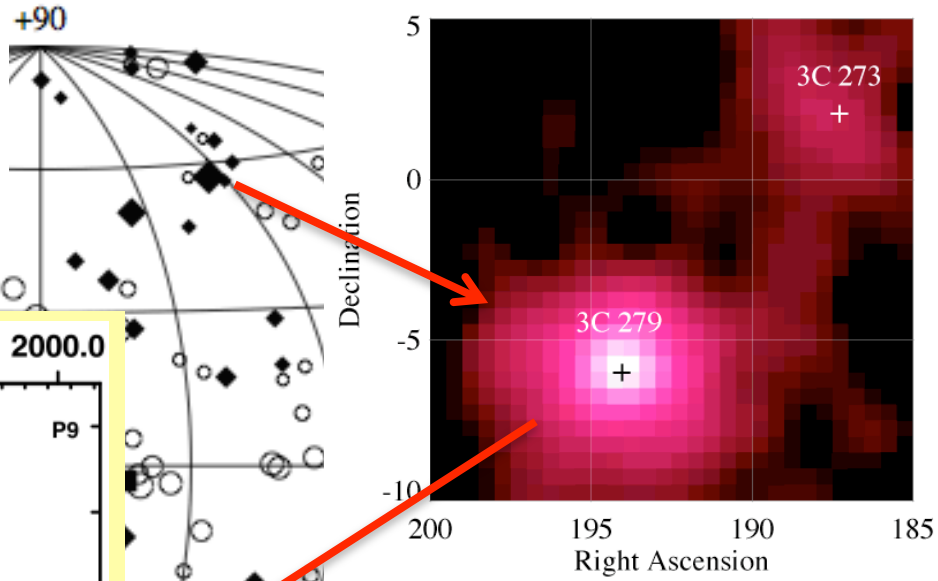
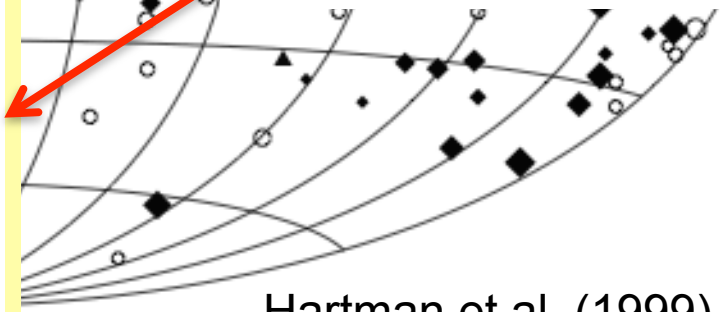
- Radio galaxies: Cen A, 3C111




Hartman et al. (2001)



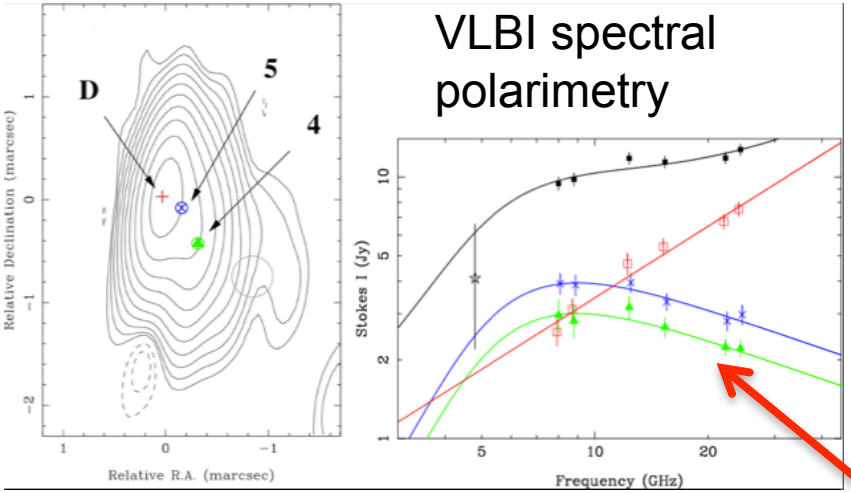
■ Pulsars
▲ LMC
● Solar FLare

Hartman et al. (1999), Casandijian & Grenier (2008)

# Fermi LAT Era: 3C279

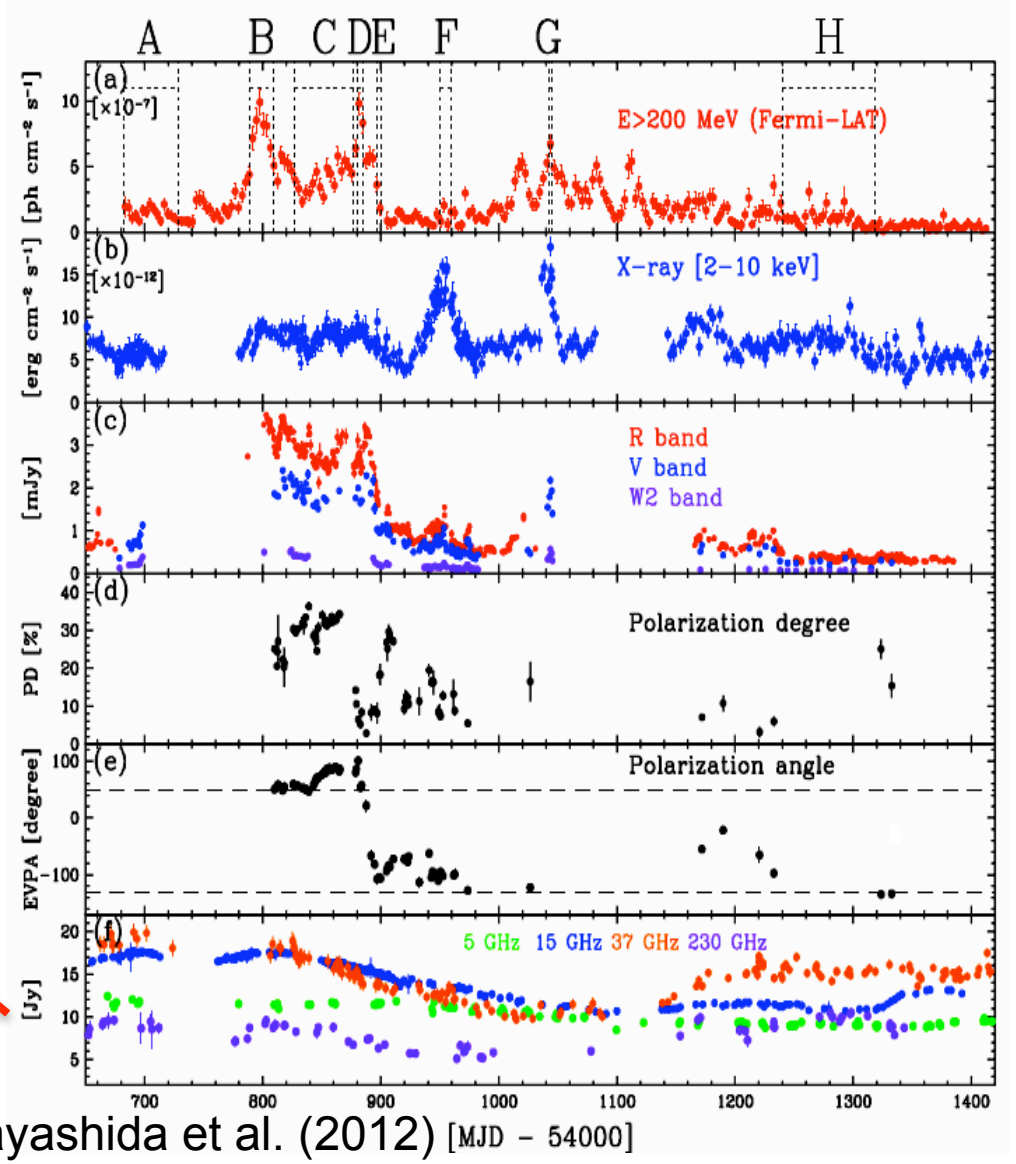
Gamma-rays connected to:

- VLBI: *Kardashev, Karouzos, Lister, Liu,* and *Abraham, D'Ammando, Orienti, Shen*
- Radio: *Hovatta, McConnell*
- Millimeter: *Tripp, Valtaoja*
- Infrared: *Massaro*




VLBI spectral polarimetry

Homan et al., MOJAVE




multi-λ, Hayashida et al. (2012)

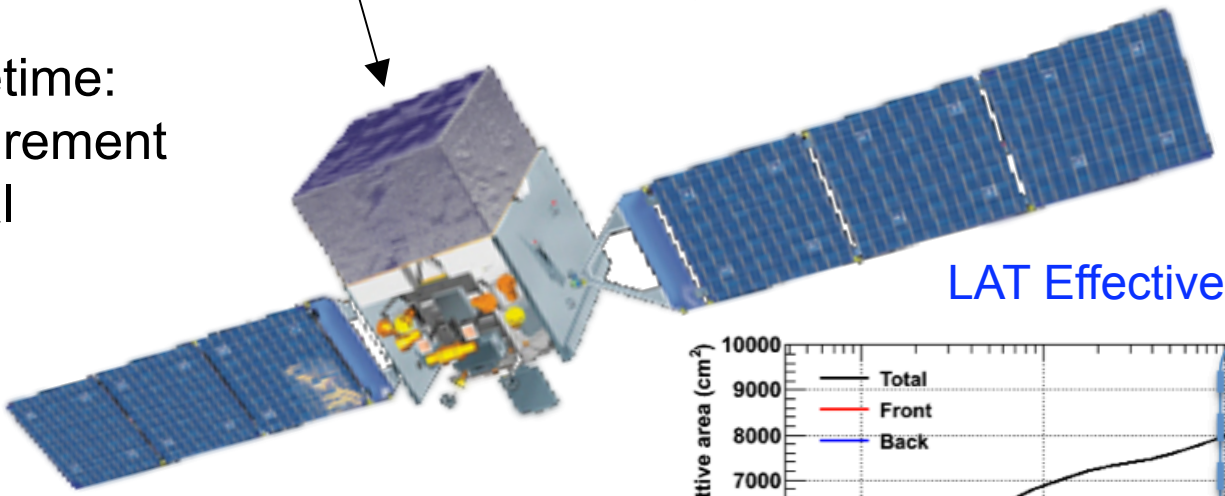
# The *Fermi* Observatory

**Large Area Telescope (LAT)**

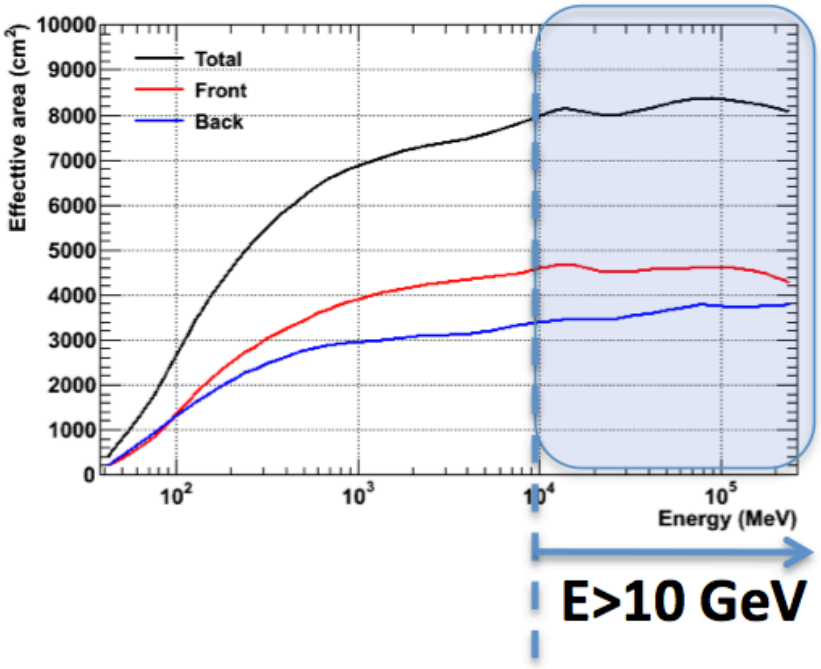
Observes 20% of the sky at any instant, views entire sky every 3 hrs

20 MeV - 300 GeV - includes unexplored region **between 10 - 100 GeV**

Mission Lifetime:
5 year requirement
10 year goal



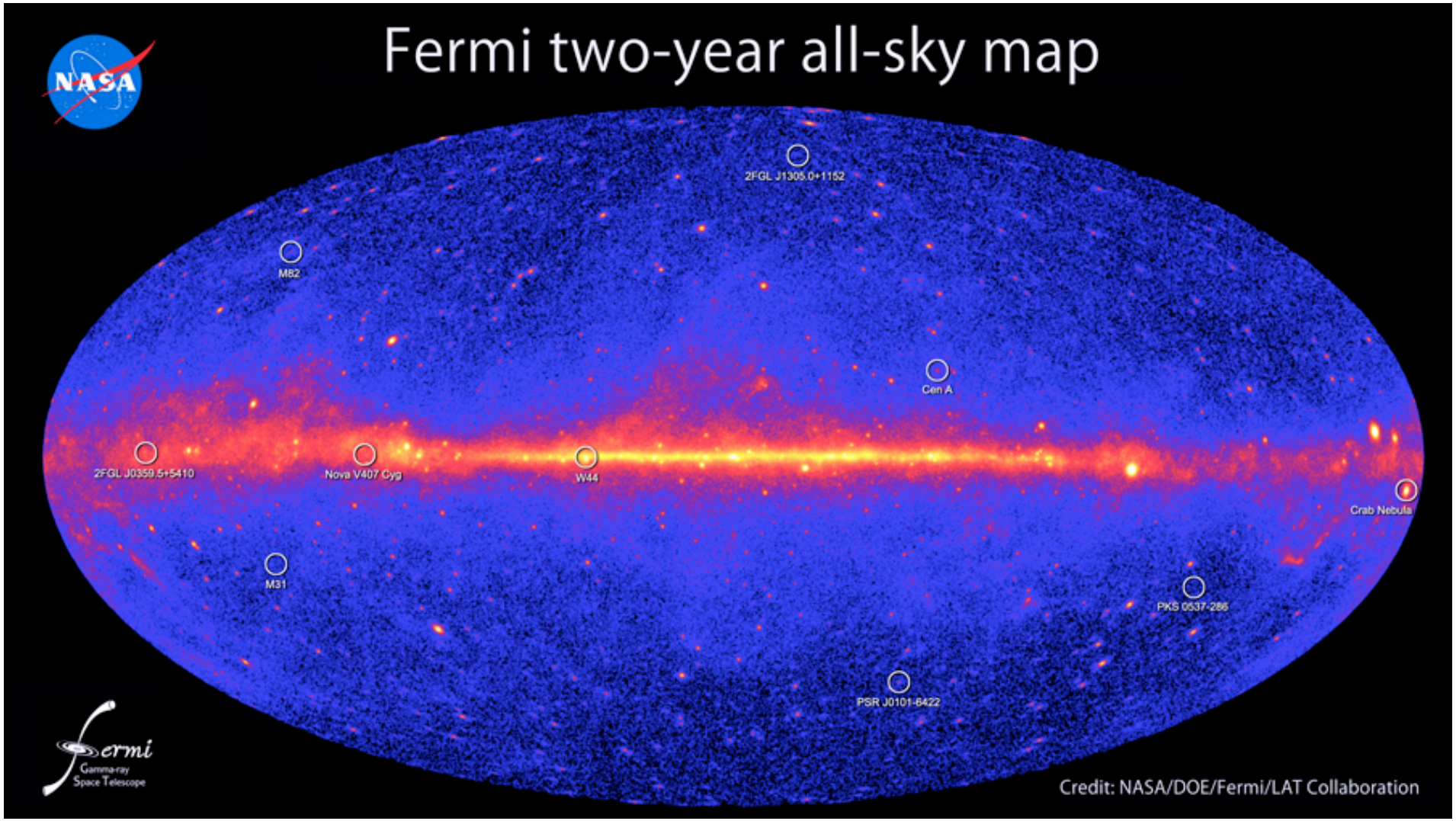
LAT Effective Area




- Unique Capabilities for GeV astrophysics
  - Large effective area
  - Good angular resolution
  - Huge energy range
  - Wide field of view

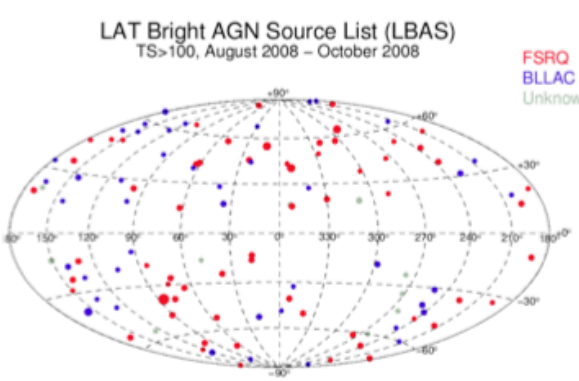
# Fermi Large Area Telescope Era

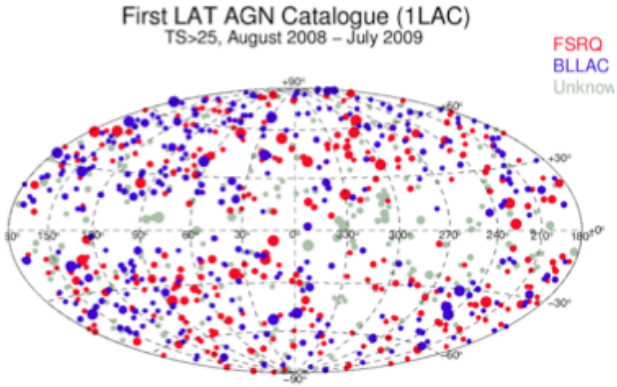
2nd Fermi-LAT Gamma-ray source Catalog (2FGL), Nolan et al (2012)

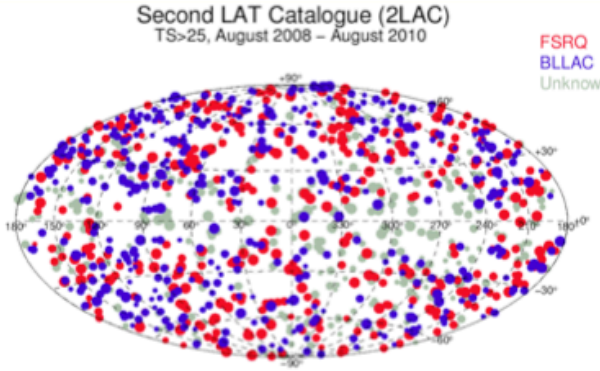


# 2nd Fermi-LAT AGN Catalog (2LAC)

**3-months** → **11-months** → **24-months**




**LBAS-high latitude:**
**58 FSRQs**
**42 BL Lacs**
**6 AGNs**

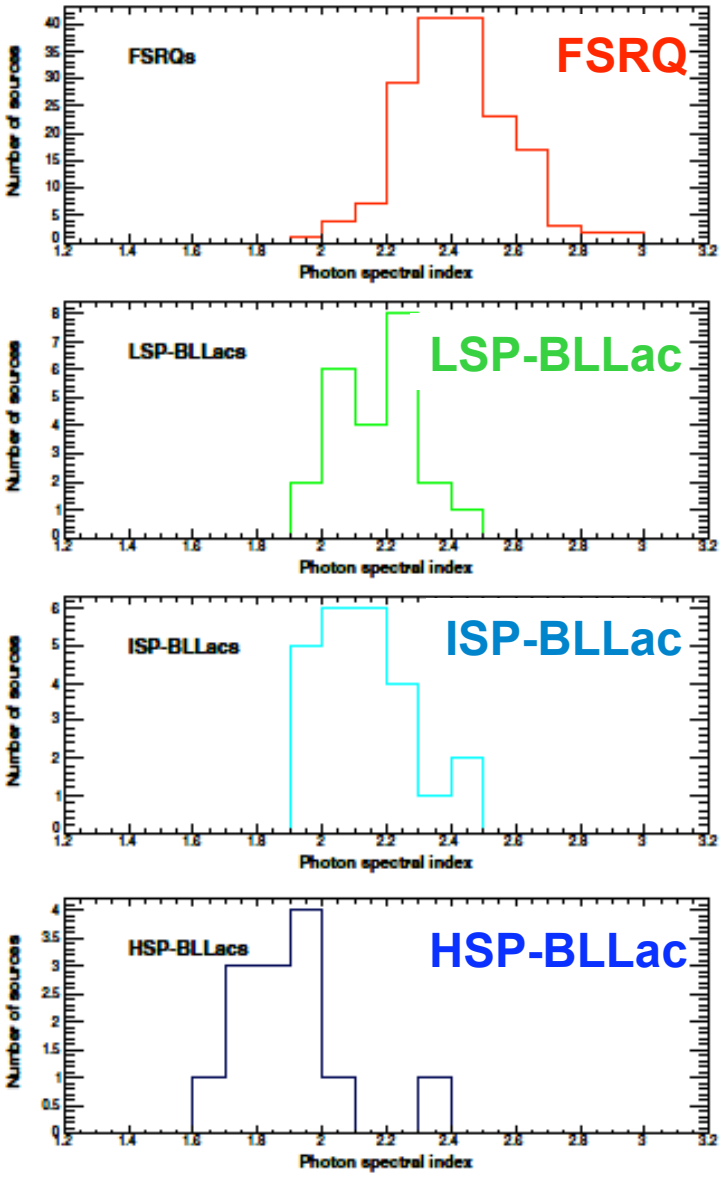
**1LAC-clean sample:**
**248 FSRQs**
**275 BL Lacs**
**50 Blazars with unknown type**
**26 AGNs**

**2LAC-clean sample:**
**310 FSRQs**
**395 BL Lacs**
**156 Blazars with unknown type**
**24 AGNs**

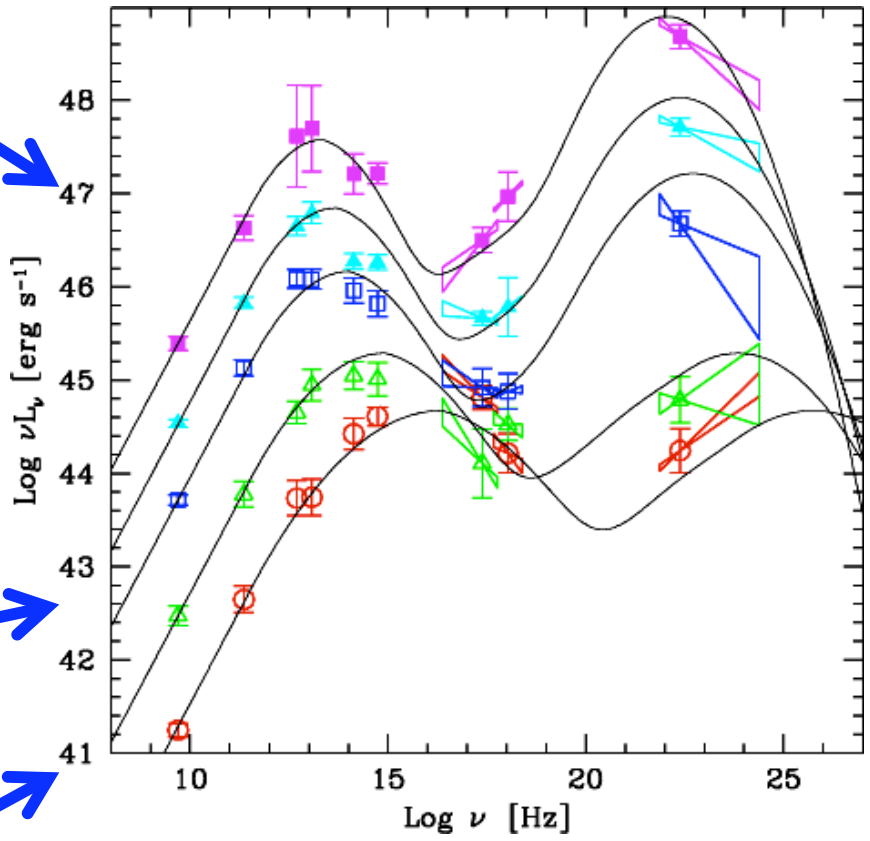
- Now ~1000 γ-ray AGN in which to study
- Largest increase in blazars of unknown type in 2LAC due to more extensive use of X-ray and radio databases, e.g., AT20G (*Sadler poster*)
- AGN = 'non-blazars' include radio galaxies – talk by *H. Sol*

Ackermann et al. (2011)

# 2LAC: Spectral Properties

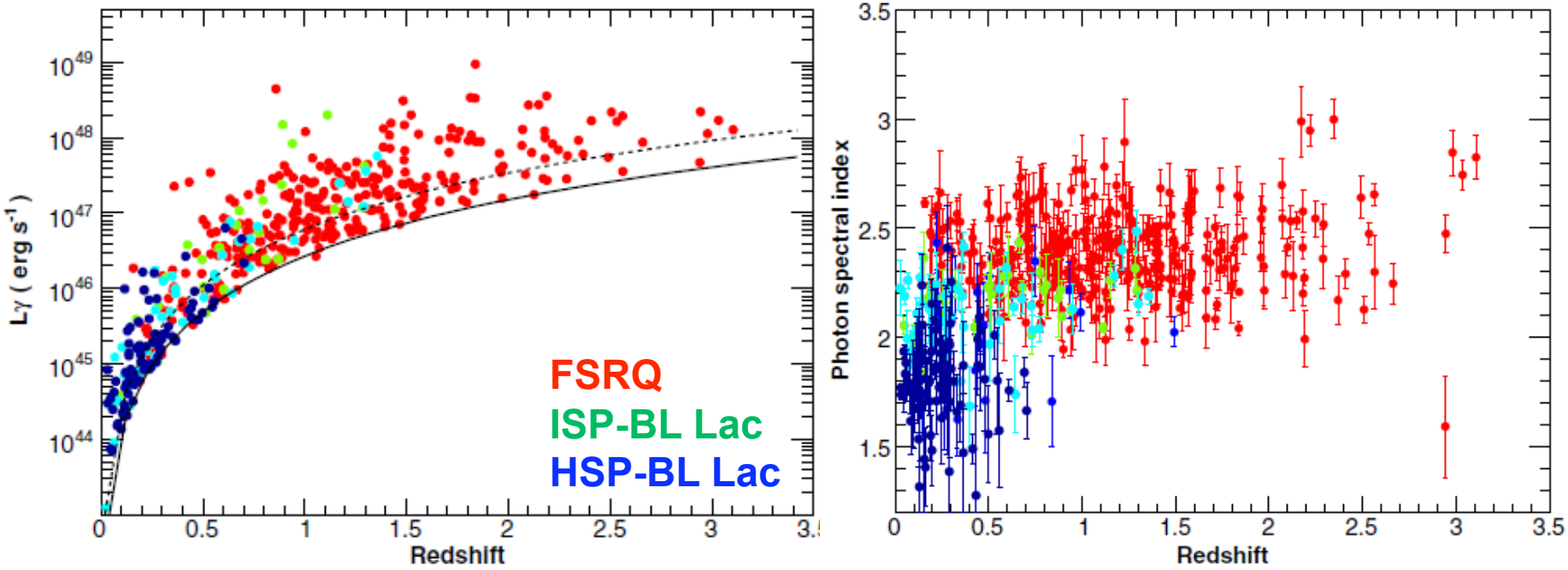



Donato et al. 2001



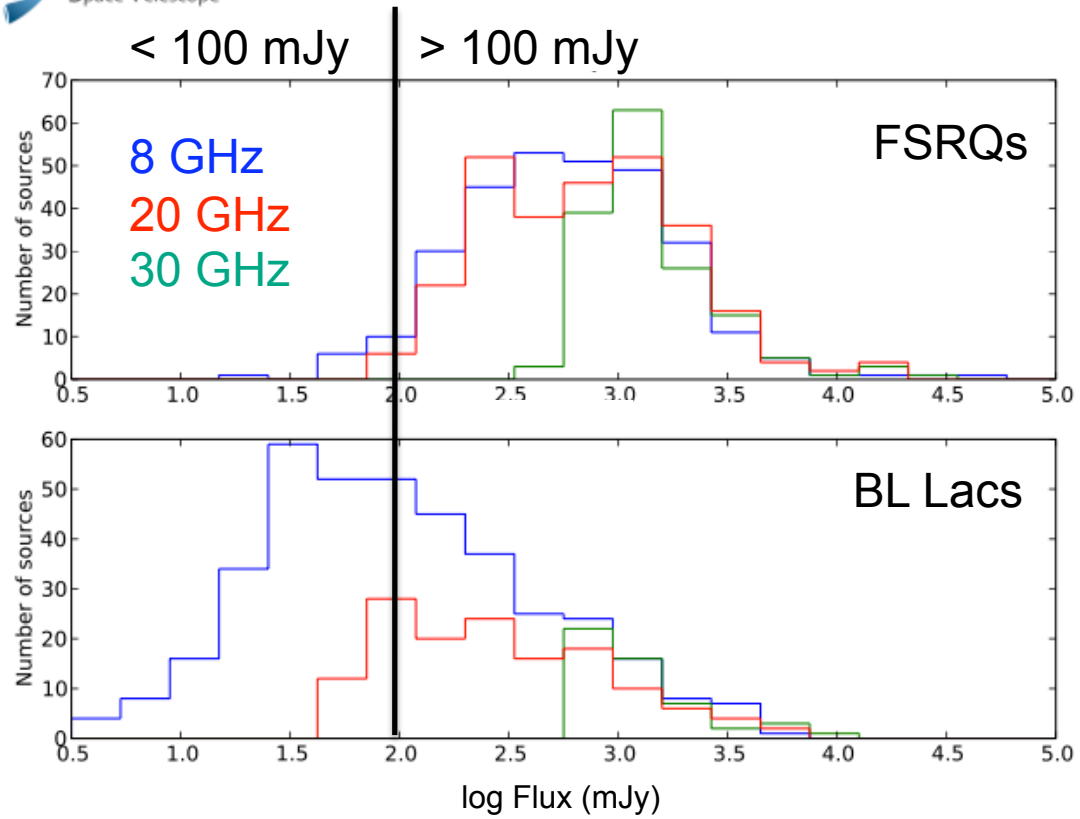

- **Strong correlation between Γ and blazar class,corresponding to *blazar sequence***

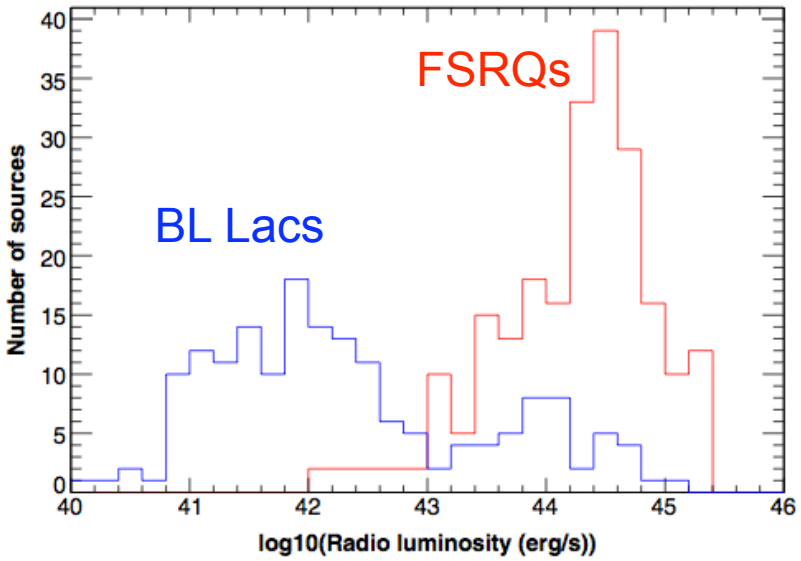
# 2LAC: $L_\gamma$, $\Gamma$ vs. Redshift




- Detection of $L_\gamma \sim 10^{48}$ erg/s FSRQs up to $z \sim 3$
- Hardest sources at lower redshifts (probably selection bias)

# 2LAC: General Radio Properties



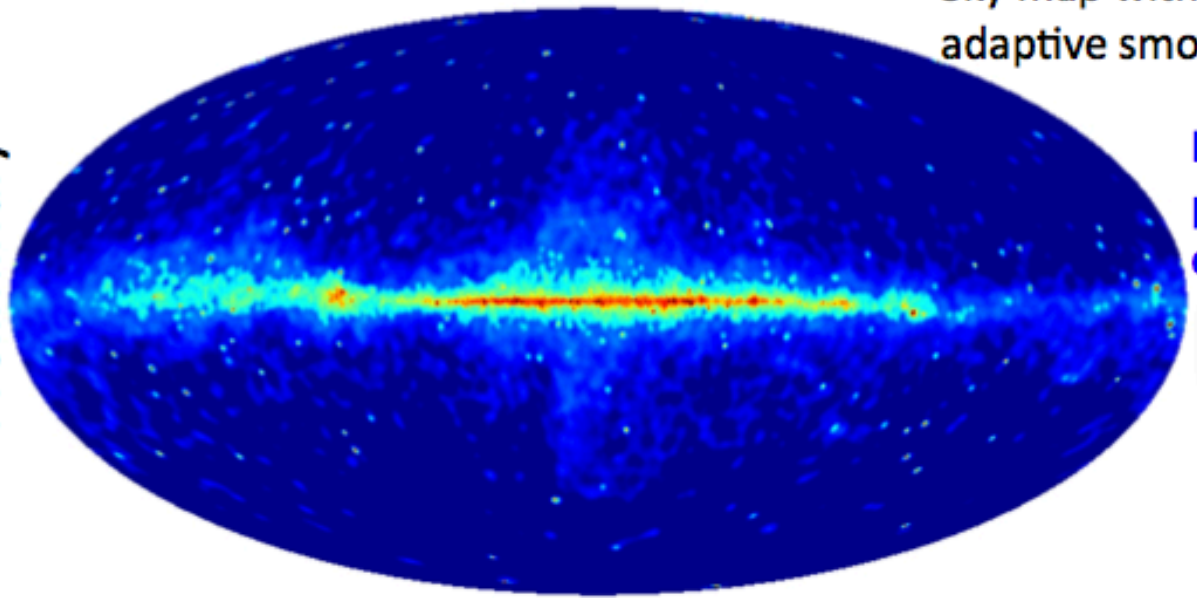

- Significant correlation between radio and gamma-ray (e.g., Ackermann et al. 2011, Ghirlanda et al. 2010, Lister et al. 2011, Lindford et al. 2011)
- FSRQs on average brighter and apparently more luminous in radio than BL Lacs (but severe redshift incompleteness)

# 1st Fermi-LAT Hard Source Catalog (1FHL)

**LAT data from August 2008 through July 2011 (nearly three years)**

**P7_V6_Clean event selection**

Sky map with > 10 GeV events and adaptive smoothing (10 photon kernel)



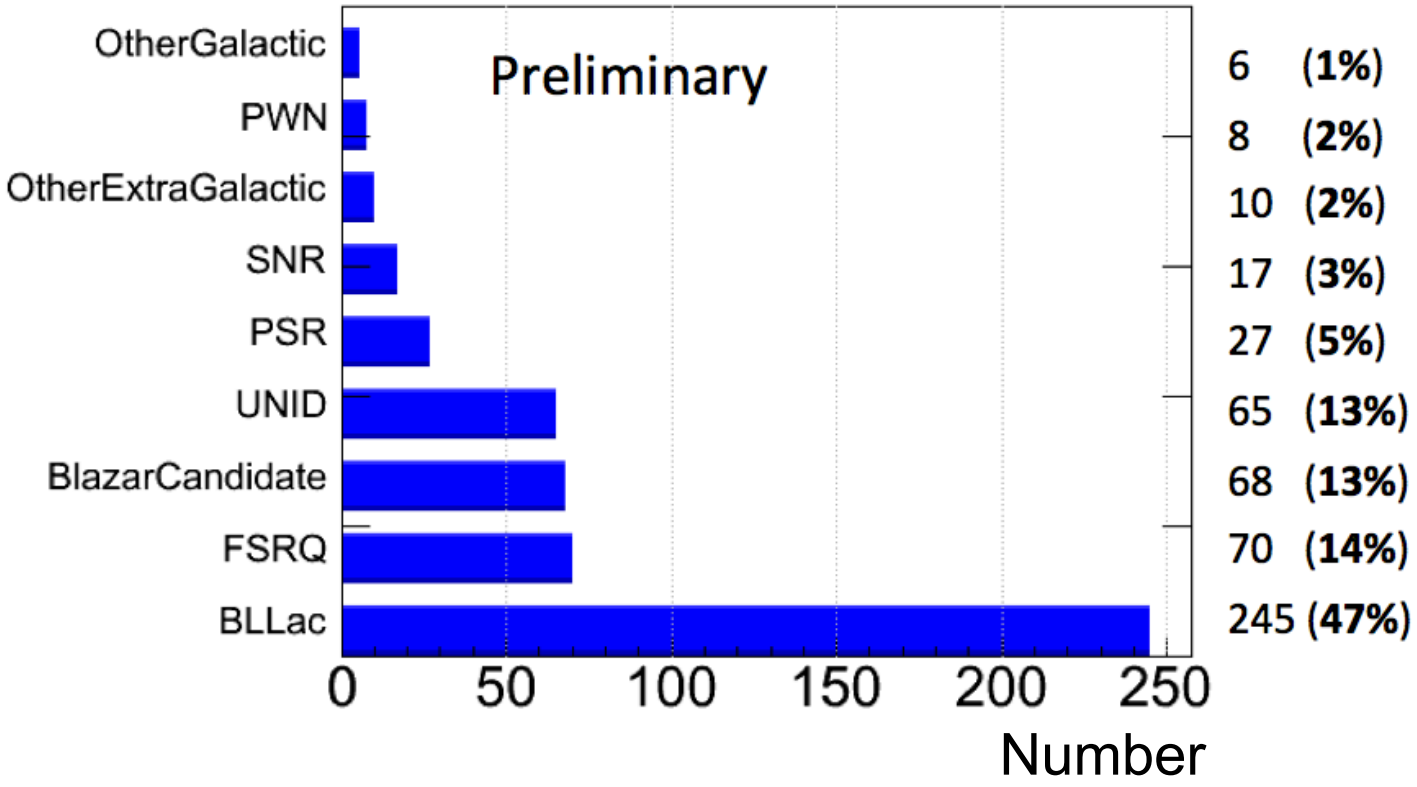

**LAT sees more than $1.5 \times 10^5$ photon candidate events in only 3 years**

**Big improvement with respect to EGRET !!!**
**$1.5 \times 10^3$ evts in 9 years**
**(Thompson et al 2005)**

- 516 sources at >10 GeV with test statistic >25 (as in 2FGL for >100 MeV)
- Flux limits at >100 GeV (3 yrs) comparable to current Cherenkov telescopes (5 hrs)

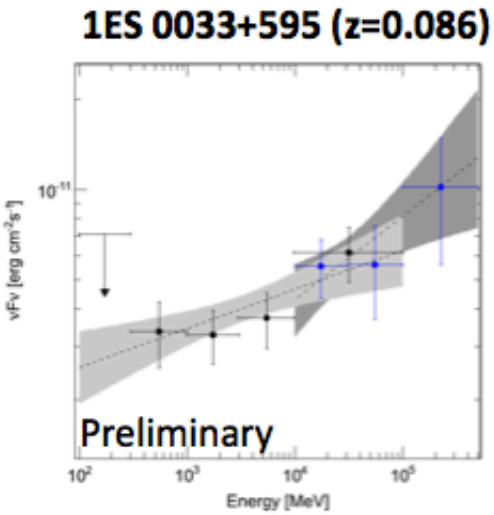
LAT team leads:
D. Paneque, P. Fortin

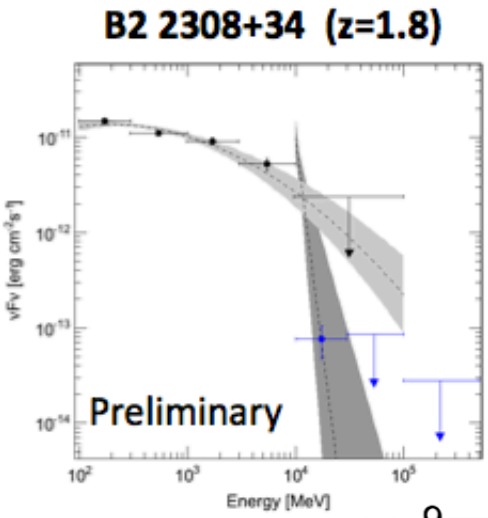
# 1FHL Census

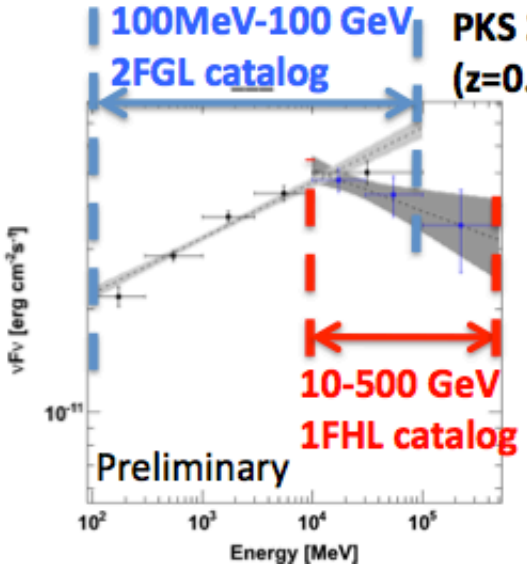



- 392 (76%) associated with AGN (373 were in 2LAC)
- 155 (42%) high-synchrotron peaked BL Lacs

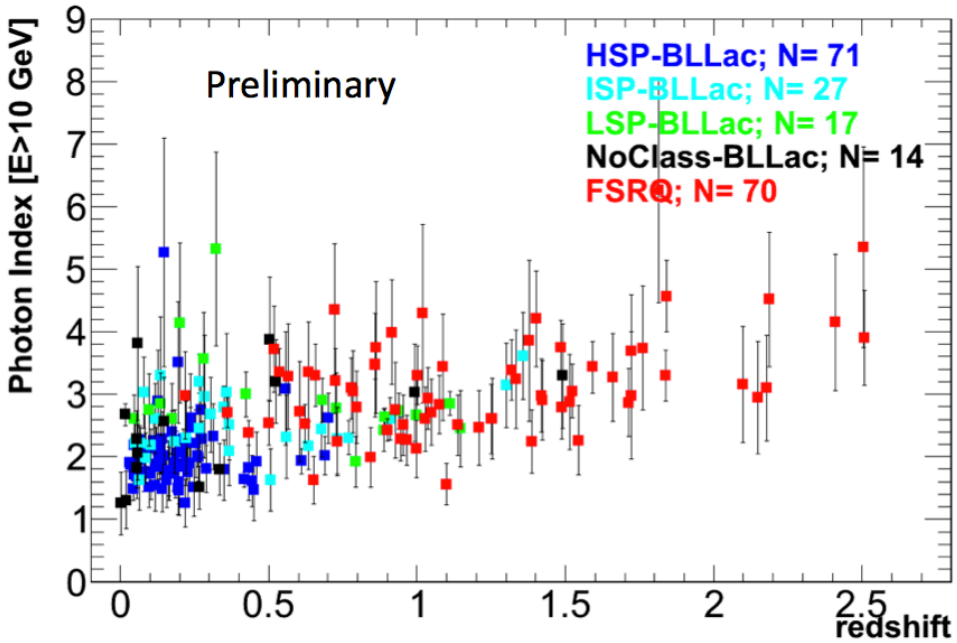
# 1FHL Spectra




- 199 sources have redshifts
- Possibly softer spectra with increasing redshift
- Targets for current and future (CTA) TeV telescopes



# Advances in Coming Years?

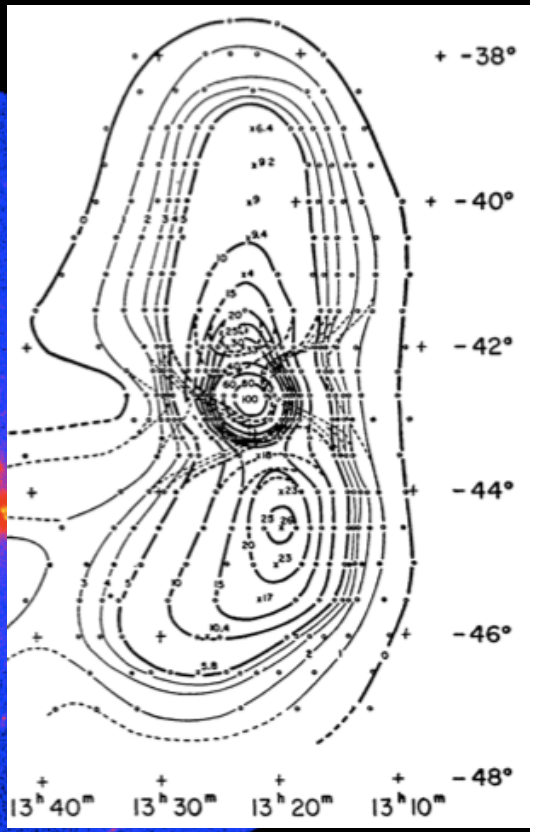
- Radio properties of the faintest, more ‘typical,’ gamma-ray AGN
  - Do radio/gamma-ray correlations extend to low fluxes/luminosities
  - How do their brightness temperatures, proper motions compare
- Possible sites of gamma-ray emission
- Young radio sources
- Radio quiet AGN and blazars

# Emission Site from Gamma-ray Imaging

NASA's Fermi telescope resolves radio galaxy Centaurus A

- LAT resolution = $0.8^{o}$ at 1GeV can *image* lobes

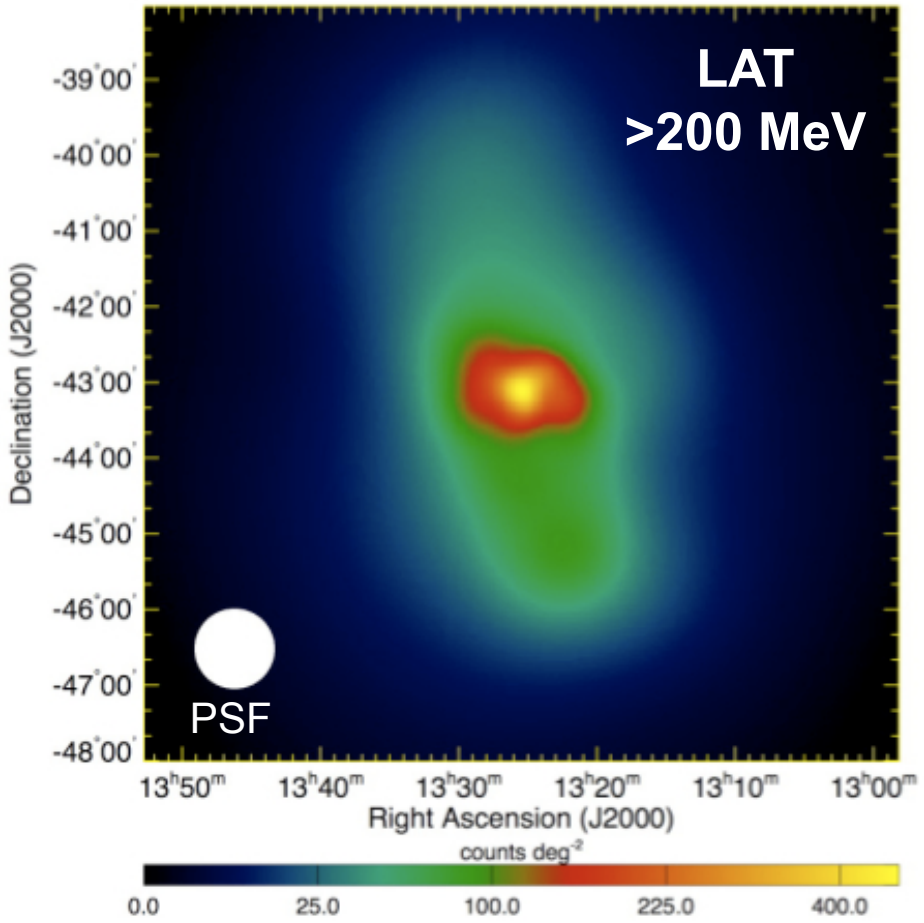
γ-ray color (purple) with optical galaxy



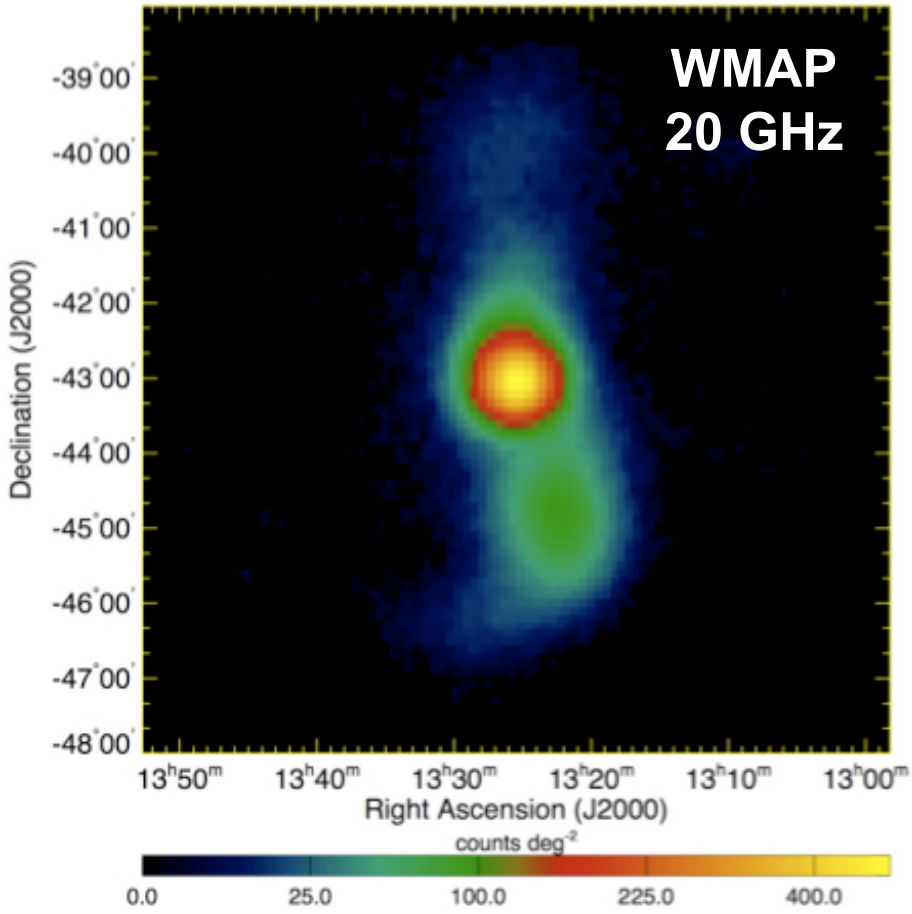

Bolton & Clark (1960)

# Emission Site from Gamma-ray Imaging

## Over ½ of the total >100 MeV observed LAT flux in the lobes



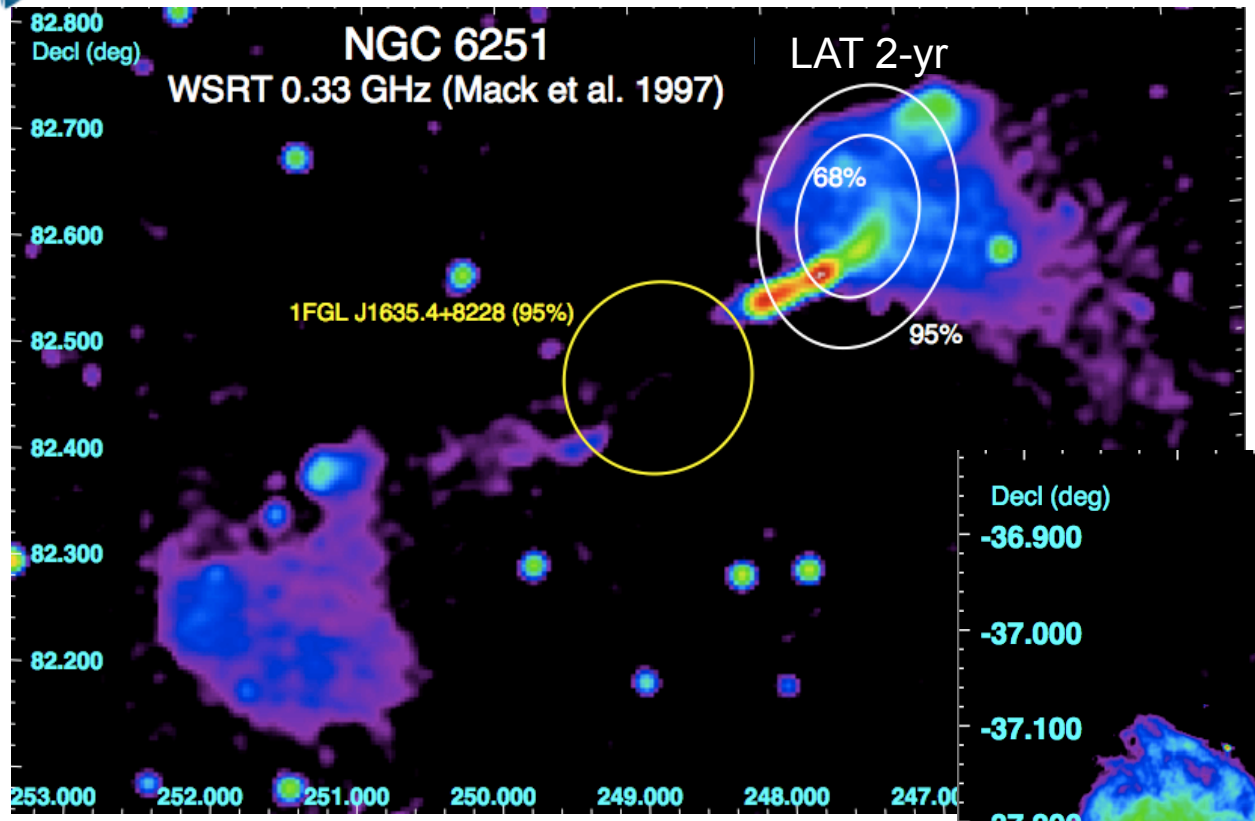

Background & point sources subtracted



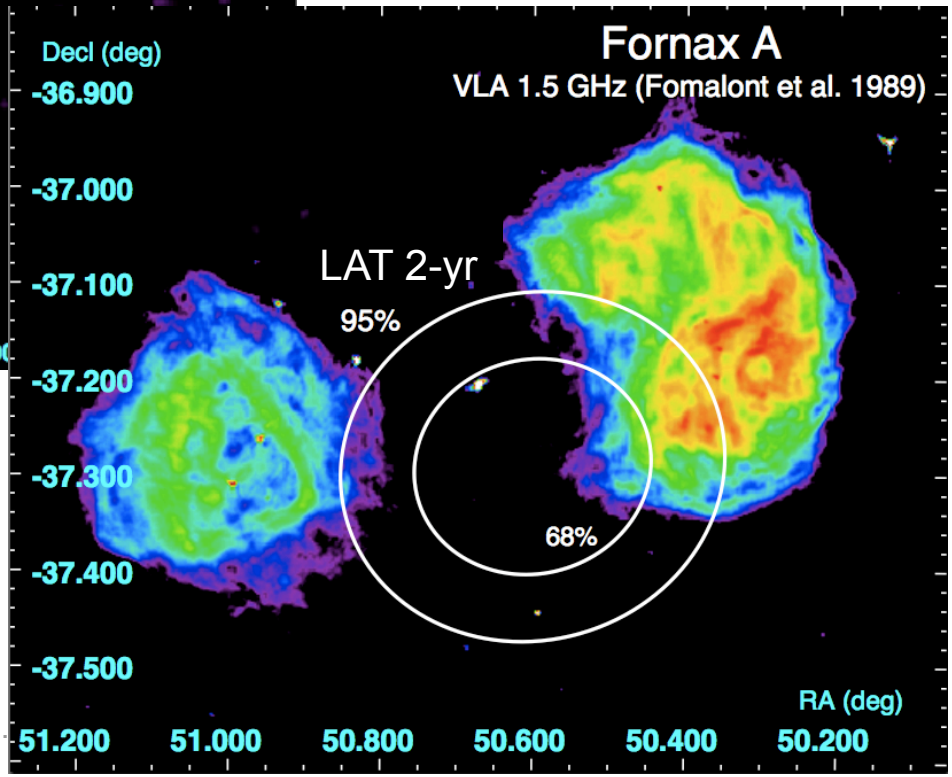

From Nils Odegard (GSFC)

Abdo et al. 2010 Science, 328, 725

# Other Inverse-Compton γ-ray Lobes?

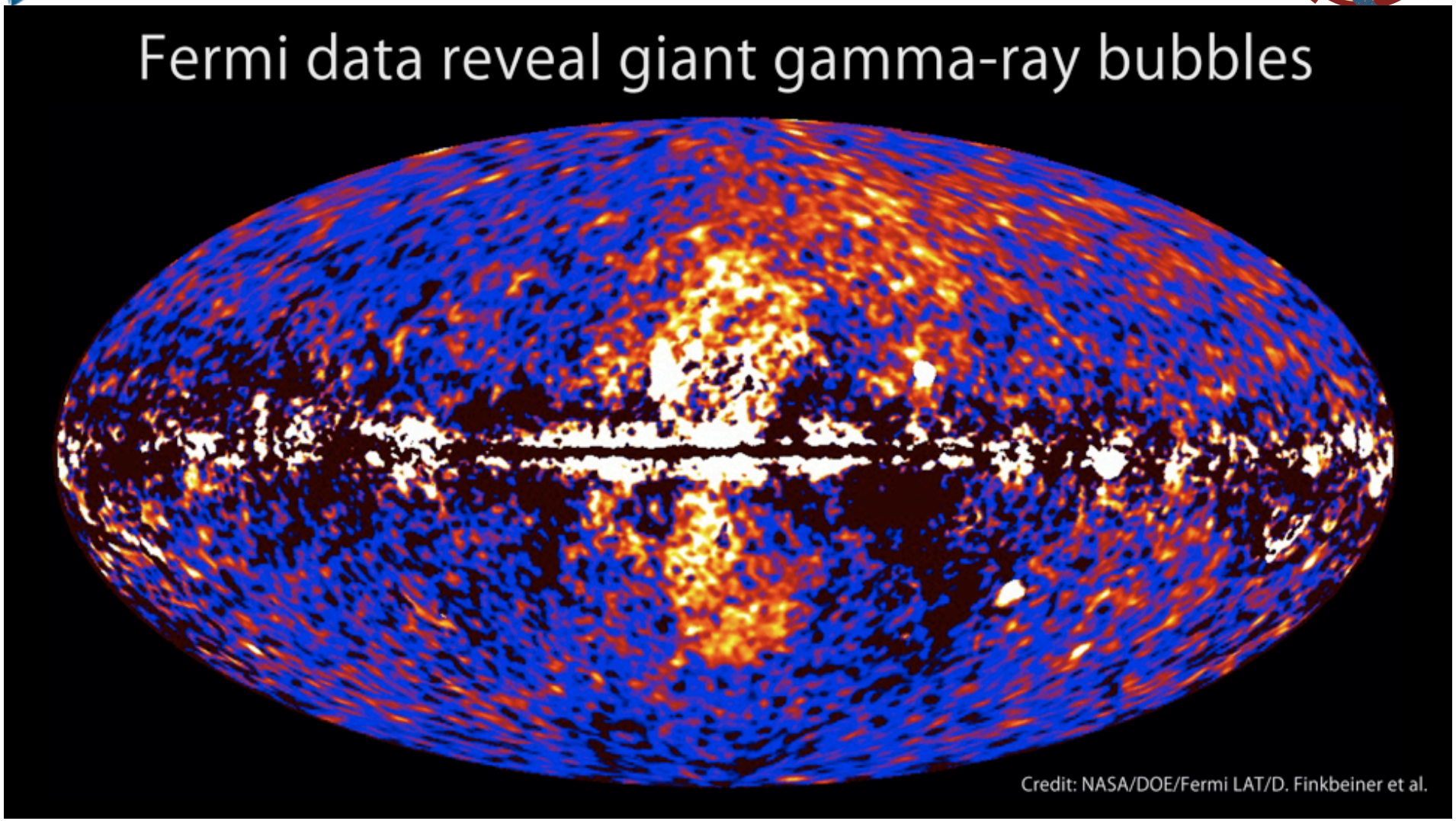



LAT 2FGL 68% and 95% confidence ellipses on radio images



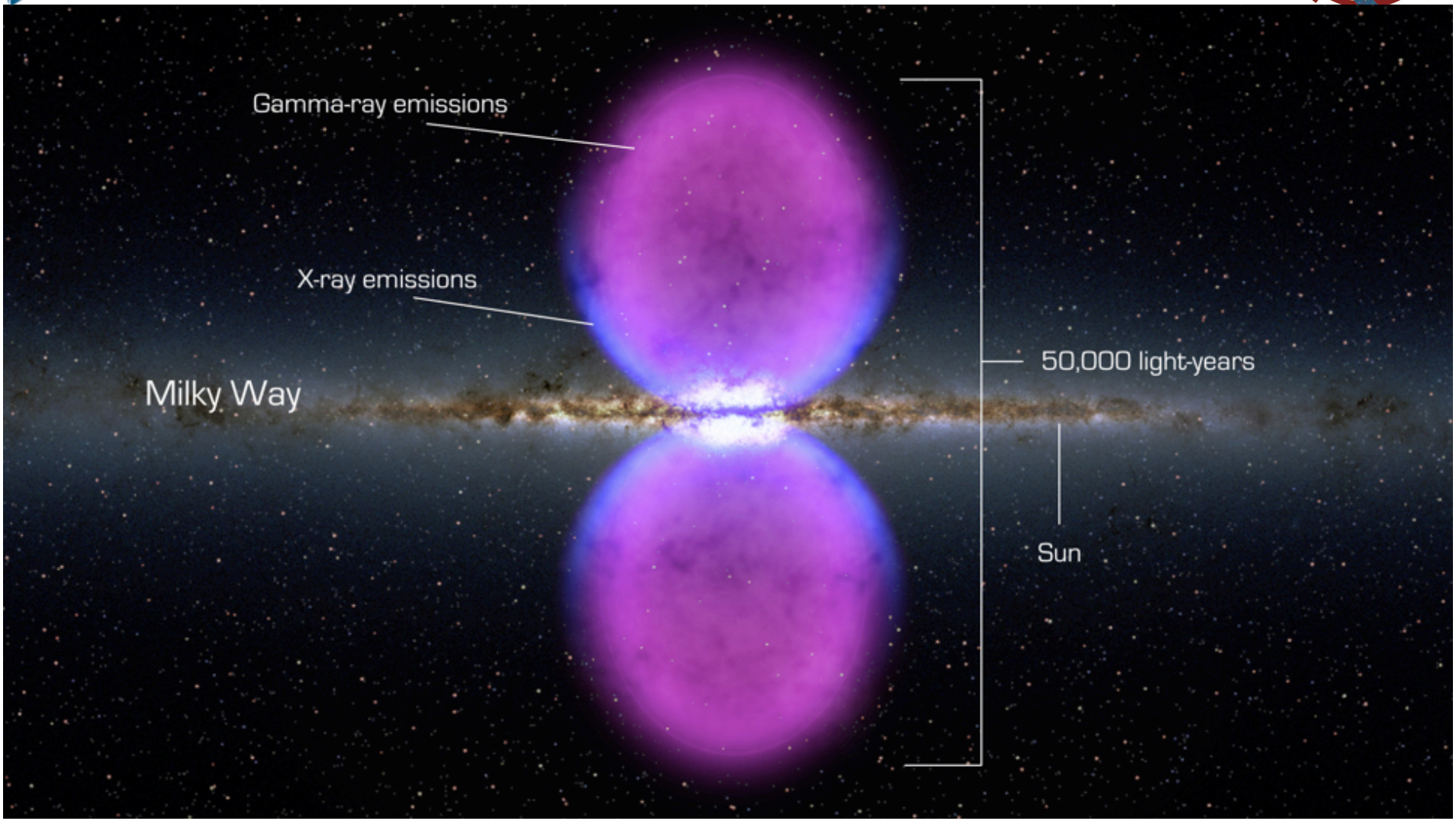

IC/X-ray lobes:
B ~ 0.4 μG NGC6251, Takeuchi+ 2012
B ~ 1.5 μG Fornax A, Feigelson+1995
And B ~ 1 μG Cen A from γ-rays only

# Our Nearest AGN




*M. Su's* talk tomorrow

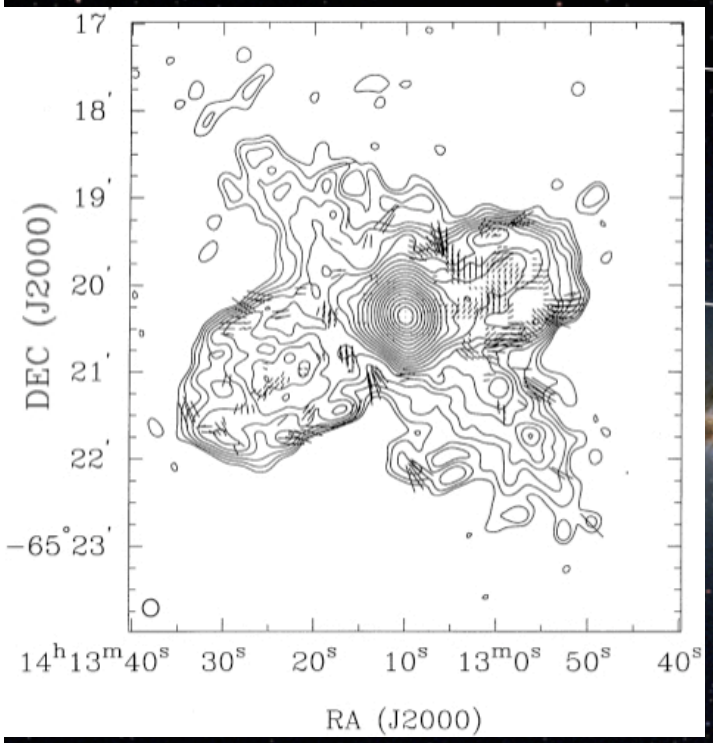
# Our Nearest AGN



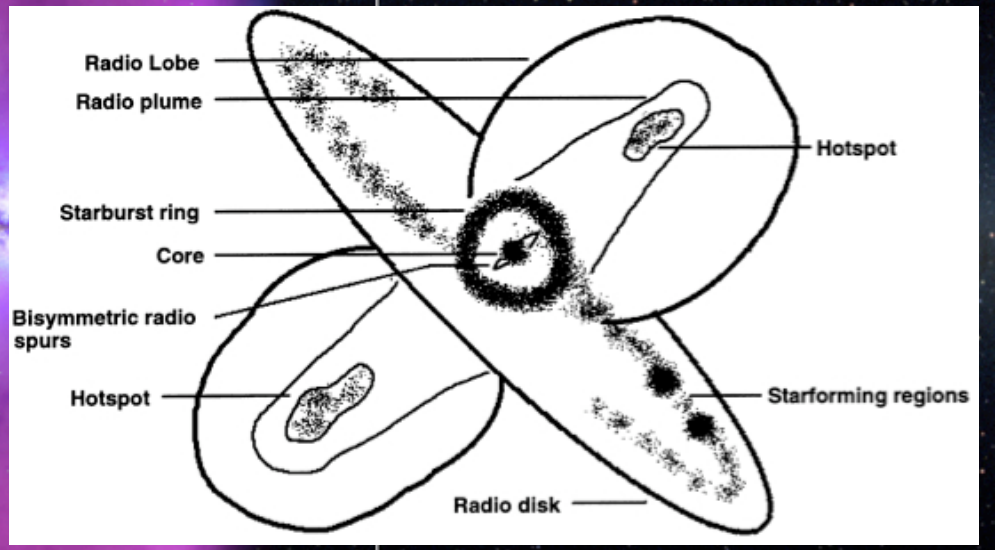

*M. Su's* talk tomorrow

# Radio Jet Activity in Nearby AGN

- Circinus galaxy (D~4 Mpc)
- Radio lobes highly polarized with extent ~6 kpc
- Hosts low-luminosity AGN

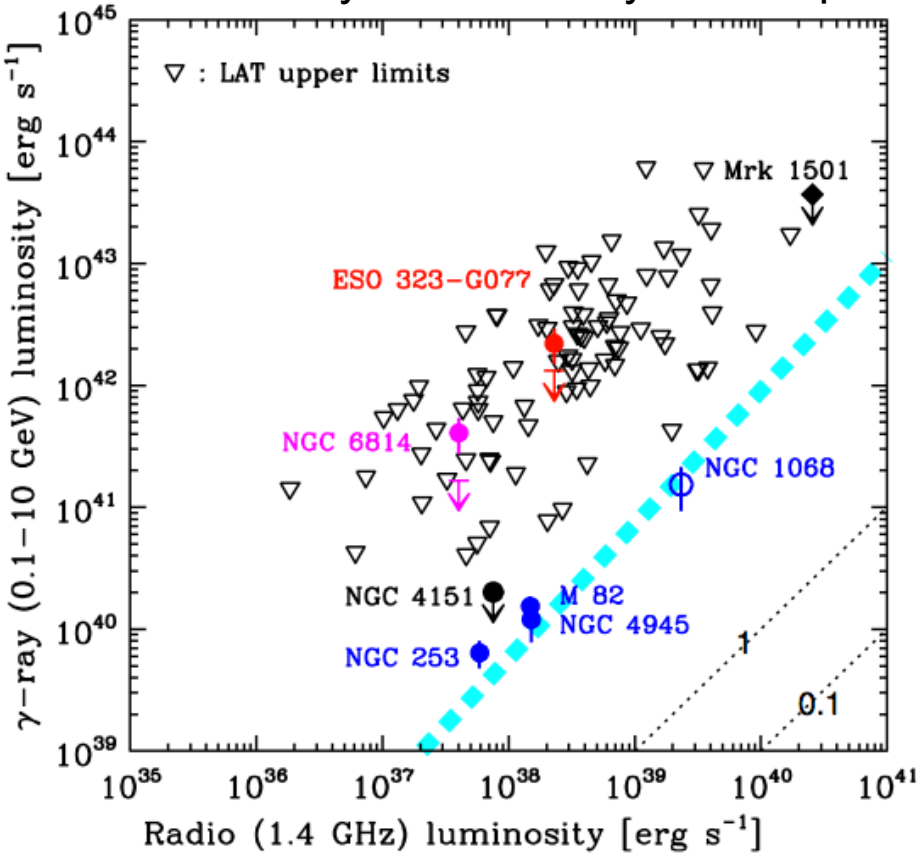



ATCA λ13cm image
Elmouttie et al. (1998)



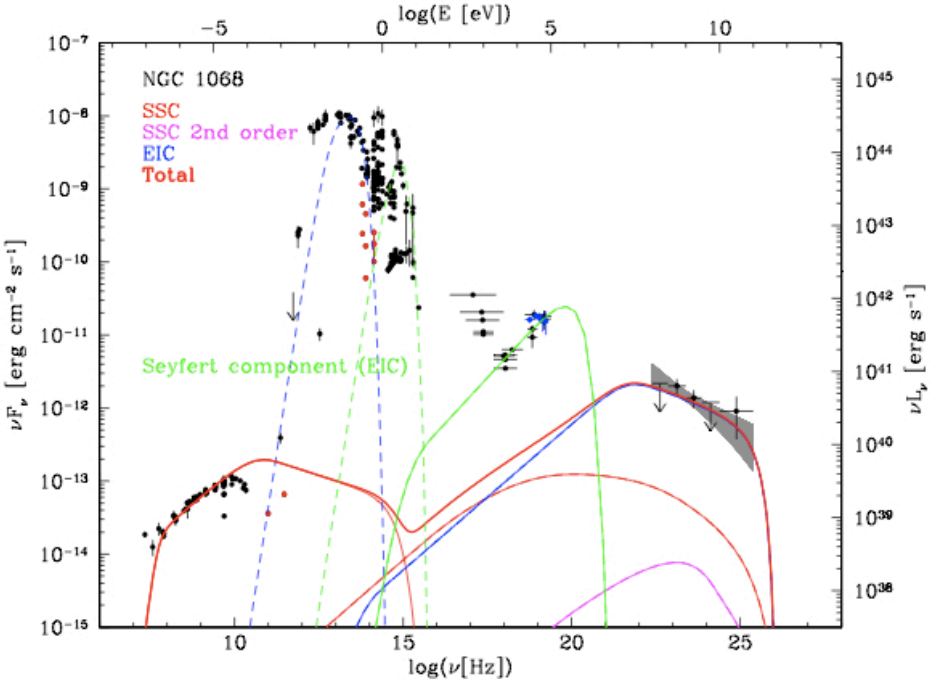
# AGN-related Gamma-rays from Seyferts?

Hard X-ray selected Seyfert sample




Ackermann et al. (2012)

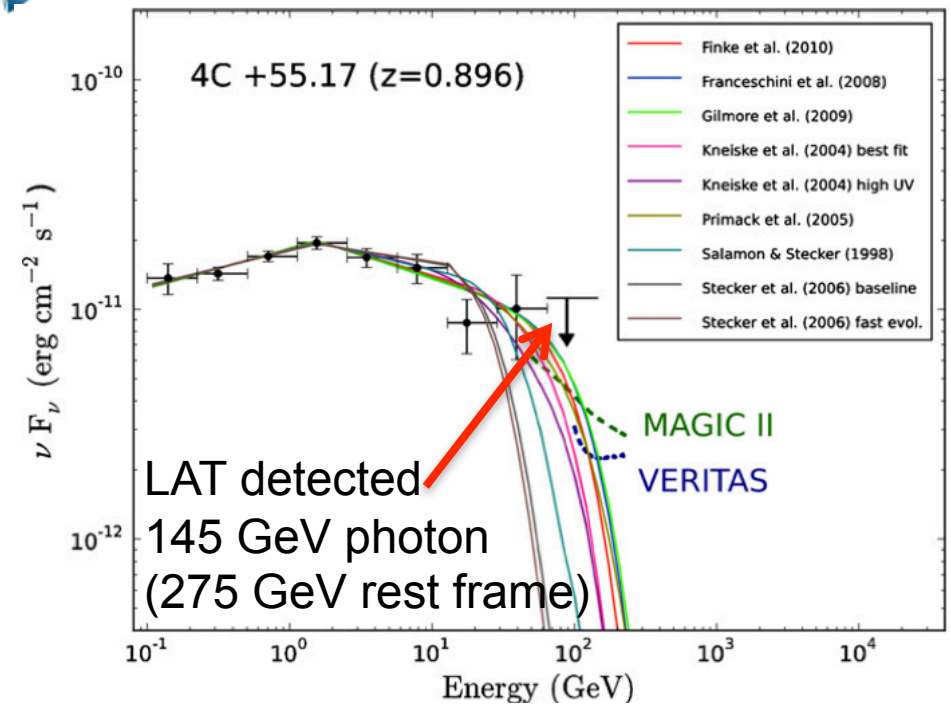
Jet model for NGC1068



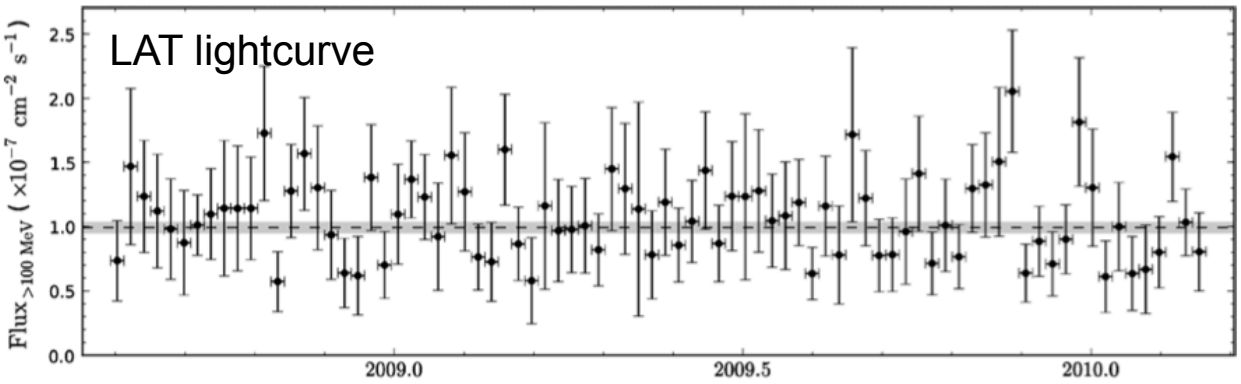

Lenain et al. (2010)

But NGC1068 (& other LAT detected nearby AGN) have prominent starbursts

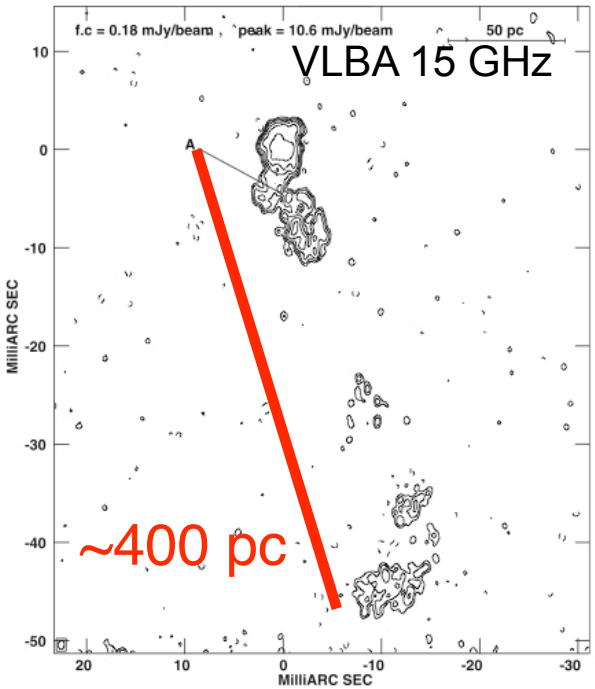
# 4C+55.17: Enigma or Keystone?




- Looks like a duck: FSRQ z=0.9
- Steady, hard MeV/GeV spectrum and resolved on VLBI scales: does not quack like a duck




McConville et al. (2011)




Rossetti et al. (2005)

# Advances in Coming Years?

- Radio properties of the faintest, more 'typical,' gamma-ray AGN
  - Do radio/gamma-ray correlations extend to low fluxes/luminosities
  - How do their brightness temperatures, proper motions compare

- Possible sites of gamma-ray emission
  - LAT imaging lobes (>kpc-scale jets): localizations, extended?
  - Correlated variability including polarization (sub-pc to pc-scales)
  - Fast variability (*Tavecchio*), gamma-ray opacity (*Poutanen*)

- Young radio sources: 4C+55.17, others?
  - Improved gamma-ray all-sky sensitivity, localization
  - Extend CSO catalogs with VLBI identifications

- Radio quiet AGN and blazars
  - Are radio quiet AGN also gamma-ray quiet?
  - Other nearby bubble sources like in our Milky Way?
  - Baby blazars (faint in radio, bright in millimeter to infrared)?